Fast Radiative Transfer with the Optimal Spectral Sampling (OSS) Technique

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Overview

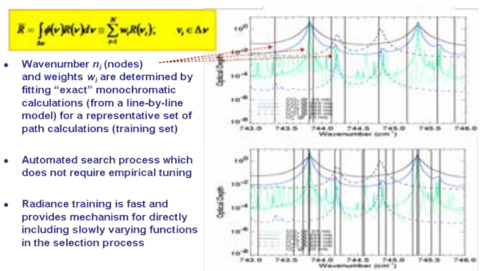
The Optimal Spectral Sampling (OSS) is a fast radiative transfer model that has been specifically designed for the modeling of radiances measured by infrared and microwave radiometers, but is applicable also through the visible and ultraviolet spectrum. OSS calculates the radiance averaged over a bandpass by calculating the monochromatic radiance at a small number (typically less than 4) of selected wavenumbers (nodes) within the bandpass and weighting the result. The nodes and weights are selected from a set of full line-by-line calculations on a number of reference profiles (the training set) which span the range of expected conditions. The selection process minimized the number of nodes for a required level of accuracy. Thus the OSS forward model reduces the number of monochromatic calculations per channel by as much as a factor of 2500, while still preserving Beers' Law.

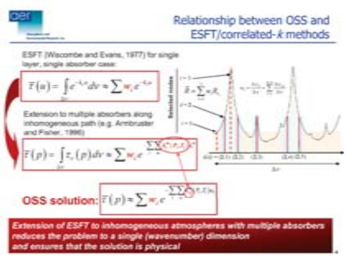
The fact that OSS is fundamentally a monochromatic method provides the ability to accurately treat surface reflectance and spectral variations of the Planck function and surface emissivity within the channel passband. In addition, the method is readily coupled to multiple scattering calculations, an important factor for treating cloudy radiances. Among the advantages of the OSS method is that its numerical accuracy, with respect to a reference line-by-line model, is selectable, allowing the model to provide whatever balance of accuracy and computational speed is optimal for a particular application. This poster discusses the application of OSS to CLARREO and its utility in understanding the radiometric signature present in the output from climate model.

Parameterization of Radiative Transfer Equation is Required for Many Applications

- Diverse remote sensing applications require radiative transfer algorithm speed, accuracy and flexibility
- Requirements for effective parameterization often conflict: high radiometric accuracy versus minimal computation time
- Available methods result in compromises:
  - Model is geared toward a specific sensor or application
  - Is not practical for use with changing observer altitude or model levels
  - Does not obey Beer's law and thus not amenable to multiple scattering atmospheres
  - Overall accuracy depends upon choice of predictors, generally determined by trial and error and depend specifically on the application (viewing geometry and spectral band), requiring re-training for alternate configurations
  - Is not directly applicable to extended instrument functions such as sinc

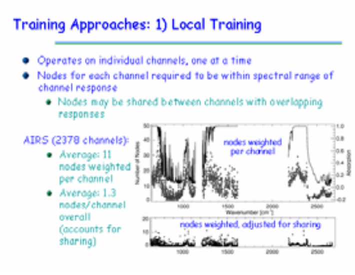
Optimal Spectral Sampling (OSS) technique designed to provide rapid, accurate radiative transfer with physical consistency for all classes of remote sensing instrumentation

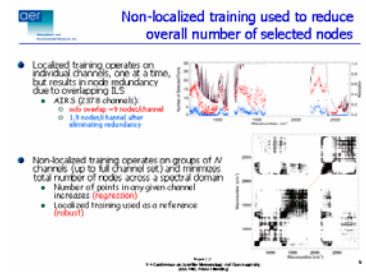




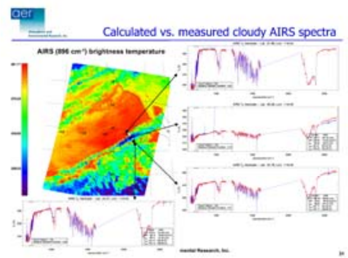
October 2008
CLARREO Workshop, Washington, DC

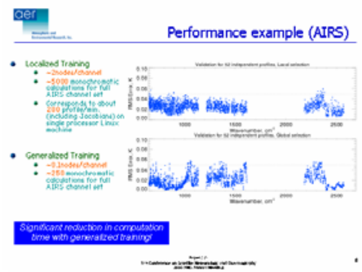
Automated Training Process to Determine Nodes and Weights

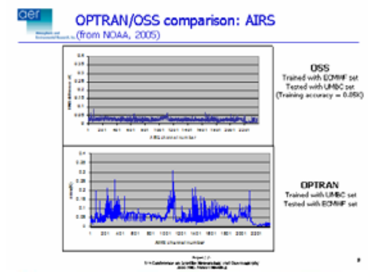


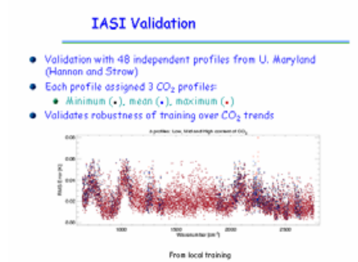


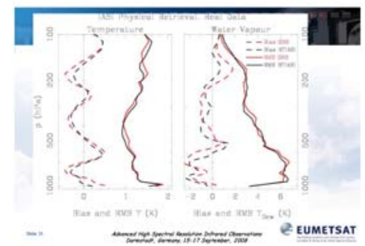
Extensive/Independent Validation on a Variety of Data

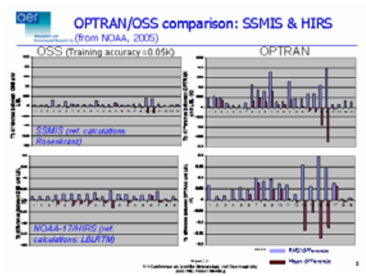


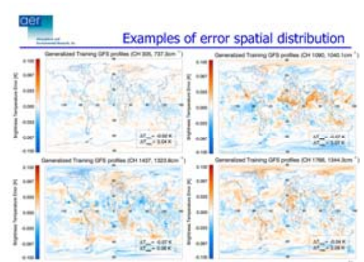












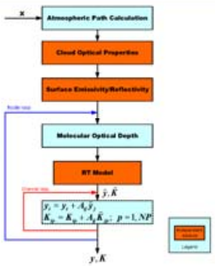
Multiple Scattering

Scattering Forward Model

- OSSSCAT is single-wavelength version of CHARTS adding-doubling RTM
  - Uses same molecular absorption and weighted monochromatic radiances as non-scattering RTM
  - Cloud module converts from physical properties (e.g., IWP, LWP, D_{eff}, top, thickness, T(p)) to optical properties (absorption and scattering optical depths, asymmetry parameter)
    - Look-up table
      - Size distributions based on in-situ aircraft measurements
      - Mie for liquid
      - MADA for ice – with temperature-dependent shape recipes
  - Optical properties linearly interpolated from hinge points to OSS nodes

OSS Forward Model

- RTM structure
  - Main loop is the node loop
  - Internal channel loop to update channel radiance and Jacobians
  - Similar structure adopted for CRTM
- LUT of *kabs* stored for all relevant molecules as a function of temperature
  - Self broadening included for water vapor
  - Maximum brightness temperature error with current LUT < 0.05K in infrared and <~0.01K in microwave
- Use simple monochromatic RT model (clear or scattering)
  - Jacobians (required for retrieval applications) are straightforward in the clear-sky (e.g. CrIS ATBD)



Multiple Scattering Acceleration

- With scattering, execution time is dominated by radiative transfer integration
  - Contrasts with non-scattering, where band transmittance calculation may be a bigger factor
  - OSS RT timing ~proportional to number of nodes
  - TPTR RT timing ~proportional to number of channels
  - OSS is faster than TPTR methods only when the number of nodes / number of channels <~1
- Scattering calculations do not have to be performed for every OSS node
  - Scattering correction may be predicted based on a few nodes only:

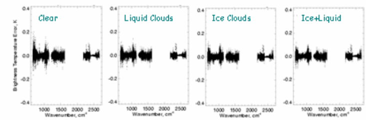
$$\bar{R} \cong \sum_{i=1}^{N} w_i R^{ns}(\nu_i) + \sum_{k \in S} C_k \left[R(\nu_k) - R^{ns}(\nu_k) \right]$$

  - R is radiance from scattering model
  - R^{ns} is radiance from non-scattering model
  - w are the ordinary OSS weights
  - k are a subset of the set of the OSS nodes (S) for the channel
  - C are regression coefficients
- Number of predictors can be tuned to control balance between cloudy radiance accuracy and computation speed
  - Some relaxation of accuracy may be tolerable in clouds with high optical depth, in proportion to uncertainties in optical properties

Cloudy and Clear Fit

- OSS selection requires accuracy threshold be met for each training set individually and simultaneously

AIRS Channel Set
Scattering included
Fit error -- all meet 0.05-K rms requirement
Nadir view shown



Scattering Prediction Performance for MODIS

MODIS Channel #	Bandpass (μm)	Number of nodes*	Number of predictor nodes†
20	3.660 - 3.840	10	4
21	3.929 - 3.989	5	2
22	3.929 - 3.989	3	2
24	4.433 - 4.498	19	2
25	4.482 - 4.549	18	2
27	6.535 - 6.895	14	1
28	7.175 - 7.475	15	2
29	8.400 - 8.700	14	3
31	10.780 - 11.280	4	1
32	11.770 - 12.270	4	1
33	13.185 - 13.485	18	1
34	13.485 - 13.785	21	1
35	13.785 - 14.085	24	1
36	14.085 - 14.385	21	1
Average		13.6	1.7

Wide-band channels, such as with MODIS are more challenging than narrow-band channels for OSS scattering efficiency, since there are more nodes/channel

Selected IR channels

Localized training used
Generalized may require fewer predictors

* for error threshold 0.05 K, clear and cloudy training
† for scattering prediction error threshold 0.2 K

Application to CLARREO

<u>OSS Incorporated into SIMRAD Infrastructure</u>

•SIMRAD developed by Stephen Leroy (Harvard) to run MODTRAN for multiple input atmospheres from climate models
•OSS module under development to improve radiative transfer timing and overall accuracy
    •Remove Jacobian calculations
•Prototype calculations conducted using nominal 3-band FTS
    •Will be expanded to full CLARREO waveband
•Scattering module under development
    •Additional timing enhancements will be required to reach CLARREO computation goals

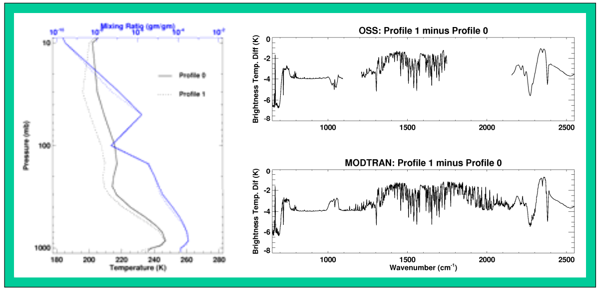
EUMETSAT Comparison of OSS and RT-IASI

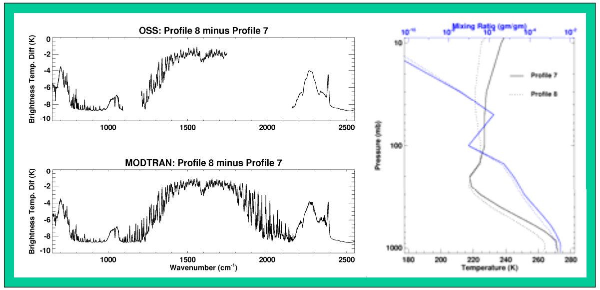
Timing Results (in sec/profile)

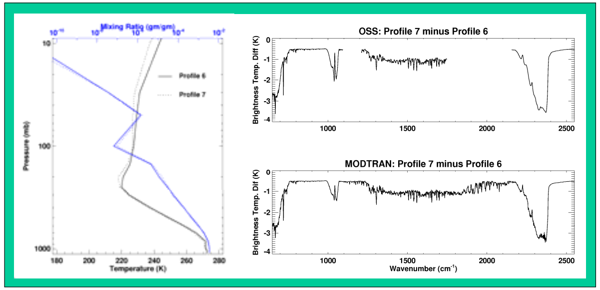
	Direct only	Direct + Jacobians
RTIASI	1.11	11.42
OSS	-	0.67

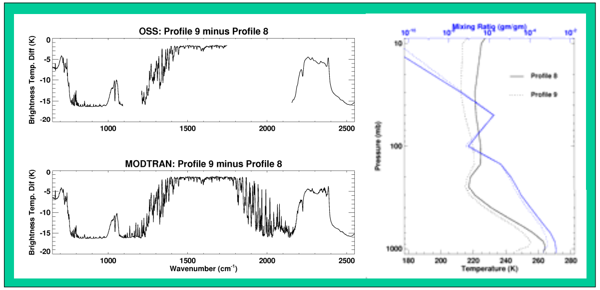
Averaged over 5308 profiles, on IBM power 2: xlf90 -O3 -q64

Brightness Temperature Differences Between Profiles Illustrate the Radiometric Impact of Changing Temperature and Water Vapor Profiles: OSS and MODTRAN Exhibit Similar Sensitivity









OSS is 3.8x Faster than MODTRAN for Clear-Sky; Cloudy-Sky Anticipated to Meet CLARREO Simulation Requirement of Less Than 1 Second per Profile

Model	Time (sec)	Spectral Elements	Profiles	Time per Profile per Spectral Element
MODTRAN	228.0	1900	600	2.0e-4
OSS	40.6	1305	600	5.2e-5

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